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Implementation of strain-life fatigue parameters estimation methods in a web-based system

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Abstract

In order to address problems connected with the choice of a proper material during early stages of product development when limited or no experimental data on candidate materials are available, a web-based information system consisting of material properties database and expert system for the estimation of cyclic and fatigue material parameters has been established. Material properties database is user-expandable and draws mainly on existing, published literature sources and results of relevant research. Besides the well-established estimation methods and the methodology for their evaluation, the results of own research in the form of a newly proposed approach and method for the estimation of strain-life fatigue parameters as well as the methodology for the evaluation of estimation methods are incorporated in the system as well.

Keywords: Strain life; parameter estimation; database; expert-system; web-based

1. Introduction

In order to shorten product development time and cut down the related expenses, simulations and virtual product testing are increasingly being performed ever earlier in the product development cycle. For modelling and simulation of the response of loaded structures and components, among other information, more or less intricate properties which describe material behaviour must be known. Except for the case of determining values of basic monotonic properties such as hardness and ultimate tensile

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Nomenclature

b	fatigue strength exponent
c	fatigue ductility exponent
E	Young's modulus
HB	Brinell hardness
MP	monotonic parameter
N	number of load cycles
N_f	number of load cycles to crack initiation
R_m	ultimate strength
$\Delta\varepsilon$	total strain range
$\Delta\varepsilon_e$	elastic strain range
$\Delta\varepsilon_p$	plastic strain range
ε_f	true fracture ductility
ε_f'	fatigue ductility coefficient
σ_f	true fracture stress
σ_f'	fatigue strength coefficient

strength, experimental characterisation of material behaviour is complicated, expensive and, in the case of cyclic i.e. fatigue experiments, it can be long-lasting as well. These are the primary reasons why alternative solutions, such as literature research and estimation methods are often resorted to in early stages of product development when numerous candidate materials are still being considered.

2. Strain-life material parameters and problems associated with obtaining them

An important task in the product development that usually has to be dealt with, is the estimation of products' lifetime, i.e. the determination and analysis of number of load reversals to crack initiation $2N_f$. For most metallic materials, the strain-life approach and the corresponding Basquin-Coffin-Manson expression

$$\frac{\Delta\varepsilon}{2}=\frac{\Delta\varepsilon_e}{2}+\frac{\Delta\varepsilon_p}{2}=\frac{\sigma_f'}{E}\left(2N_f\right)^b+\varepsilon_f'\left(2N_f\right)^c \tag{1}$$

(or one of its modifications) are widely used, due to their practicality and existence of extensive knowledge base [1]. Unsurprisingly, problems in obtaining Basquin-Coffin-Manson fatigue parameters σ_f', b, ε_f' and c are very much those already mentioned in the introduction.

Their experiment-based determination, while certainly most accurate, soon becomes prohibitive due to the already mentioned complexities, long duration and high costs of cyclic experiments, especially if more different materials must be evaluated.

Existing material data from the literature, although numerous, are often of limited availability. Due to the nature of the their origin and different forms and formats that data are reported in, virtually no methods for their inquiry and comparison exist. Furthermore, significant number of experimental results are published in specialized and/or scientific publications and for the most part remain unknown and inaccessible to the majority of users from the industry.

Since monotonic tensile tests are simple and inexpensive, and their results usually readily available, one of the methods for the estimation of strain based approach fatigue parameters from monotonic material properties [2–8] is often used in circumstances when strain-life parameters are required. In Table 1, the list of most prominent methods and their key parameters is given.

Table 1. Key estimation parameters and constants of most prominent methods for the estimation of strain life fatigue parameters

Estimation method	σ_f'	b	ε_f'	c
Original universal slopes method (1965) [2]	R_m	–0,12	ε_f	–0,6
Four-point correlation method (1965) [2]	b, E, R_m, ε_f	ε_f	c, ε_f	b, E, R_m, ε_f
Method by Mitchell (1977) [3] – Steels	R_m	R_m	ε_f	–0,5 or –0,6
Modified universal slopes method (1988) [4]	E, R_m	–0,09	E, R_m, ε_f	–0,56
Uniform material law (1990) [5] – Unalloyed and low-alloy steels	R_m	–0,087	E, R_m	–0,58
Uniform material law (1990) [5] – Al and Ti alloys	R_m	–0,095	0,35	–0,69
Modified four-point correlation method (1993) [6]	R_m, ε_f	E, R_m	ε_f	E, R_m, ε_f, σ_f
Hardness method (2000) [7] – Steels	HB (R_m)	–0,09	E, HB	–0,56
Medians method (2004) [8] – Steels	R_m	–0,09	0,45	–0,59
Medians method (2004) [8] – Al alloys	R_m	–0,11	0,28	–0,66

However, the problem with estimation methods is that there is no universal or "the best" method which could be applied to all material groups with equal success. For their utilization, adequate knowledge is required, as not all methods are equally suitable for all materials and their conditions – a fact which is often overlooked in practice.

3. Web-based material properties information system

Proper choice of the material suitable for a specific application is one of the most important and complex issues that need to be addressed during product development. With ever increasing possibilities of numerical simulations, there is a requirement that this task be successfully completed already during initial stage of design process. If experimental testing of all candidate materials cannot be performed, which is usually the case, it is suggested that the quality and accuracy of material selection can be improved by:

- increasing the degree of availability, searchability and comparability of existing knowledge on materials,
- developing better estimation methods and improving the accuracy and reliability of existing ones,
- educating end users, i.e. expanding the knowledge on proper application of estimation methods of material behaviour.

For the purpose of fulfillments of above mentioned goals, web-based information system has been developed and established at the address www.matdat.com consisting of:

- a dedicated webpage containing general information with additional function of being an entering point for those interested in perusing the information system,
- an interactive and user-expandable knowledge base and material properties database containing design-oriented data on properties of design-relevant metallic materials,
- a knowledge-based expert system, featuring a set of rules and tools for an optimal choice of a suitable estimation method and for the estimation of the required advanced material parameters from available monotonic properties, such as the ultimate strength R_m or Brinell hardness HB.

Additional benefits expected to result from the implementation and employment of the mentioned information system can be summarized as:

- increased level of utilization of experimental equipment, as well as of experts' work and knowledge,
- easier and faster evaluation of the suitability of more candidate materials during product development,
- savings due to the avoidance of repeating experiments and tests already performed elsewhere with the same or similar materials,
- increasing possibilities of verification of own experimental results,
- facilitation of investigations and research requiring data on large number of materials,
- dissemination of knowledge on advanced material models and an increase of their acceptance by practicing engineers and experts from the industry.

4. Estimation of cyclic and fatigue parameters from monotonic properties

An important part of the proposed system is an expert system consisting of a set of rules, methods and tools for the estimation of both cyclic and fatigue parameters from monotonic properties of the material. Although expert systems dealing with the estimation of fatigue and certain monotonic properties already exist [9-11], unlike the proposed solution they are not web-based.

Within the expert system as a part of developed web-based system, straightforward estimations of fatigue parameters can be performed by simply choosing and applying a particular method of estimation. However, more sophisticated options within the scope of the implemented knowledge-based expert system are available to non-specialist users lacking the expert knowledge which is required if an appropriate estimation method is to be used. The knowledge-base and the rules implemented in the developed expert system combine several already known estimation methods [2-8] and the established methodology for their evaluation [12] with the results of own research – a recently proposed novel approach and method for parameter estimation and the methodology for the evaluation of estimation methods [13] and [14].

The newly proposed approach to the estimation of fatigue parameters [13] and [14] and the corresponding estimation method incorporated in the system are based on the idea that since in the strain life approach the fatigue life of the material is defined by $\Delta\varepsilon/2$–$2N_f$ relationship (1), the estimation of the strain life fatigue parameters should be based on the analysis of actual, empirical strain life data as well. New approach aims to ensure that numbers of load reversals to crack initiation $2N_f$, calculated using the estimated values of fatigue parameters, are as close as possible to those obtained experimentally. Instead of directly and independently correlating monotonic with fatigue parameters, this is achieved by the identification and the establishment of relationships between the chosen monotonic parameter *MP* and $\Delta\varepsilon/2$–$2N_f$ relations. From these relationships, *new* values of fatigue parameters σ_f', b, ε_f' and c can then be determined for a given value of the chosen monotonic parameter *MP*. One of the essential advantages of this new approach is that the fatigue parameters are not estimated individually, i.e. independently from one another. In order to improve its accuracy, this method distinguishes between unalloyed, low-alloy and high-alloy steels, as well as aluminium and titanium alloys [15]. In addition to being accurate, it is of utmost importance for an estimation method to be practical. Hence, being convenient and easily obtainable monotonic properties, hardness and, alternatively, ultimate strength R_m, were chosen, as a monotonic parameter *MP* from which fatigue parameters are estimated. These two properties are strongly correlated, so that the value of one of them can be easily and quite reliably determined, if the value of the other one is known [14].

In accordance to the own evaluation methodology, proposed in [13], in addition to the performance of parameter estimation methods across the entire fatigue range, their performance within the low-cycle and the high-cycle fatigue ranges should be evaluated separately. In order to further improve its own validity and accuracy, the implemented procedures for the evaluation of individual parameter estimation methods and their mutual comparison draw on the content of the material properties database. Additional advantage is that contents of the database are continuously being updated with data from literature that become available as well as with contributions made by the users of the system.

5. Conclusion

As it was already mentioned previously, proper choice of the material is one of the most important and complex issues that need to be addressed during product development. With ever increasing possibilities of numerical simulations, there is a requirement that this task be successfully completed already in the initial stage of the design. In order to facilitate an easier and faster fulfillment of these requirements, a web-based material properties database and an expert system for the estimation of cyclic and fatigue properties of metallic materials has been established. It is expected that it might be of use to improve the accuracy of preliminary calculations of load carrying capacity as well as of calculations of number of load reversals/cycles to crack initiation, which are increasingly being performed at early stages of product development, when limited or no experimental material data are available. However, in addition to this direct benefit, the system is also intended to increase the availability, searchability and comparability of the existing knowledge on materials and methods of estimation of their cyclic and fatigue parameters.

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